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ABSTRACT

This study compared industry and higher education links in the flow measuring and electronic component industries in the United Kingdom, France, and Belgium. The research analysis looked at how academic research priorities have been shaped by the demands of industry and why some sections of British industry fail to take opportunities presented by the resources of the science base. The study conducted case study interviews with representative of the 47 firms, surveyed academics in related fields, conducted case studies of six national laboratories, and interviewed policymakers, representatives of trade associations, and other interested parties. Analysis of findings suggested that regulation has caused the science base, particularly in electronics, in each country to be increasingly caught up in an information market. In addition each country was found to provide different levels of uncertainty to industry in the kind of research undertaken and the skills of scientists and engineers. A major factor influencing exploitation of the science base was interaction between people in industry and the science bases. Such interactions create essential networks, provide vital training for both sides and give critical insights into respective roles and expectations of participants. (Contains 33 references.) (JB)

The public and private interface in technology: The regulation of industry and academic links

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Abstract

In an increasingly complex competitive situation, firms look to outside technological resources to supplement and substitute for expensive in-house effort. The use by industry of national laboratories and universities (the science base) is usually seen in terms of the transfer of technology out of universities. In reality, what is increasingly happening is that the ideas and problems of industry are first transferred into the science base. This has implications for the control and direction of scientific research. The paper illustrates the implications of this current trend for the control and direction of scientific research by discussing the findings of a recent study. This compared industry and academic links in two industries in three countries: the flow measuring and electronic component industries, in the UK, France and Belgium.

INTRODUCTION

Information has become an economic commodity. This is because innovation, which is based on information, is the cornerstone of industrial competitiveness. Innovation is expensive; it requires capital equipment and workforce skills. Investment in both involves risk due to uncertainties of outcomes. In order to maximise their use of resources, and reduce risk, it has become an increasing tendency for firms to externalise some of their innovation activities to other organisations. These include other firms, and universities and national laboratories (the science base), (usually) at a price. Such information transfer constitutes a market transaction.

The market for information suffers from all kinds of failure because of inefficiencies associated with free markets. In a totally free market, all research would be conducted in the private sector. However, this is not the case. And, when governments are involved, market failures are introduced. This is because governance of universities is institutionally rather than market based, as market mechanisms alone lead to an under investment in research (and development) in a market economy (see Rosenberg 1990, 166). It is for this reason that governments finance most fundamental research and a certain amount of radical innovation (Freeman 1982, 168). This has the effect of reducing the risk to industry of the uncertainties of longer term research investment. Further, inefficiencies would arise where industry did not appropriate the benefits of public sector research.

The current political interest in the UK and other countries in the interface between private and public technology arises from the conviction that these inefficiencies are detrimental to economic performance. Therefore, regulation is designed to provide the means to encourage greater exploitation of scientific and technological resources. However, residual problems exist as a result of particular measures, which can take a long time to be fully appreciated.

This paper looks at the implications of past and current regulatory practices using some examples from the electronic components and flow measuring industries in the UK, France and Belgium. At issue are (1) the extent to which academic research priorities have been shaped by the demands of industry, and (2) why some sections of British industry fail to take the opportunities presented by the resources of the science base.

The paper is organised into four further sections. The first describes the research, the second introduces examples of how the regulatory framework operates, the third discusses the research findings and the fourth reaches some conclusions.

THE RESEARCH

Introduction

Recent social science research (e.g. Charles and Howells 1992; Lawton Smith 1993) has begun to explore the impact which regulation has on the relationship between industries and the science base. Problems in this kind of research are that the tools for analysis are still being developed and processes are not fully understood, not least because of the interacting forces of political and technological change. It is argued here that the dynamics of time and space are central to an understanding of the regulatory process. In order to provide some context to the discussion, historical and geographically specific characteristics of the science base and the industries are introduced.

The science base

The organisation of the science base in the UK is more similar to that in Belgium than in France. In the UK and Belgium, universities and national laboratories have been the major focus of public sector research. However, in France, more science base research tends to be in non-university public sector laboratories, particularly National Centre for Scientific Research (CNRS) laboratories. The CNRS operates under the Ministry of Research and Technology (MRT). Universities per se play a relatively weak role in research (Atkinson et al 1990, 5).

In the UK, national laboratories operating under the aegis of the UKAEA, MoD, Science and Engineering Research Council (SERC) and Department of Trade and Industry (DTI) traditionally have been locations of fundamental research. This is now changing with political priorities which bring national laboratories in competition with both industry and universities. The establishment of the Defence Research Agency (DRA), the Monopolies and Mergers Commission investigation into the UKAEA, and the proposed privatisation of national laboratories are obvious manifestations of the political process of commodification of public funded research. Similar patterns exist in France and Belgium, particularly with regard to the roles of atomic energy laboratories.

The UK has the strongest research base in flow measurement of the three countries. Scientific research in flow measurement in the UK until recently was focused through the Flow Measuring Instrumentation Consortium (FLOMIC), formed in 1987. Until its demise in May 1993, a victim of the recession, it was funded entirely by subscription. At its peak it had some 25 industrial members, both users and manufacturers, plus ten academic members and the National Engineering Laboratory (NEL). In electronics, in the UK, universities and RSRE Malvern, and to a lesser extent Harwell, are foci of science base research.

Mixed CNRS and university laboratories are important centres of research in France. Key roles are also played by other national laboratories (grandes organisms) such as in telecommunications. University/CNRS research in flow measurement is undertaken in a handful of departments, plus the Centre d'Etudes et de Recherches de Toulouse (CERT). In electronics, the Commissariat A' L'Energie Atomique (CEA) laboratory Laboratoire De'Electronique De Technologie et D'Instrumentation (LETI), is a major player.

In Belgium, the research base is very strong in electronics. In particular the Inter-university Micro-Electronics Centre (IMEC) is a major regional, national and international resource. Research into flow measurement is confined to a small number of academics.

The Industries

The industries were chosen because of their common feature: that they both affect the competitive position of firms in other industries, although they differ in scale and economic importance. Electronic components is a core industry, and nearly every industry measures flows of gases, liquids and solids - for example petrol, chemicals, food, and the utilities.

Later discussion of the findings from the research will illustrate the differences in the degree and quality of interaction with the science base resulting from where an industry is generally excluded from positive public authority support (flow measurement) and when considerable resources are applied to its support (electronic components). However, as we will show, some common patterns emerge.

The Flow Measuring Industry

Flow measurement is one of the most important process measurement variables, being used for monitoring, control, fiscal and legal purposes in a wide range of industries and utilities (Sanderson 1989). As a manufacturing industry, the flow measurement industry world-wide is in the order of £450M-500M/annum. However, the total world-wide value of industrial output that depends on flow metering is of the order of £6,000bn/annum (Kinghorn 1987).

The UK is by far the most important of the three countries in terms of research and industrial activity. The UK has some 200 manufacturers and suppliers, France at most 30, and Belgium less than 20 (mostly sales offices) and now only a handful of manufacturers. The industry is dominated by multinational companies which are challenged by a decreasing number of smaller independent companies operating in niche markets.

The electronic components industry

The electronic components industry is classified into 9/10 component groups. Europe as a whole is orientated towards industrial, military and telecommunications applications. The UK has some 700 manufacturing sites, employing 90,000 (DTI 1990). France has over 600 manufacturers and suppliers, employing some 40,000 people in 1983 (Moulaert and Swyngedouw 1992). Belgium has about 25 manufacturers and suppliers. Much of the electronics industry is telecommunications; and is foreign owned, by mainly French and German parent companies.

Methodology

The empirical research took the form of:

* case study interviews with a sample of 22 electronic component and 25 flow measurement firms in three European countries between October 1990 and September 1992

* a survey of academics in related scientific fields in the UK, France and Belgium

* case studies of six national laboratories

* interviews with policy makers, trade associations and other interested parties in each country.

The interviews set out to investigate three things. Firstly, firms' motivation for interaction with the science base. Secondly, the experiences of industry. Thirdly, the views of scientists and engineers in the science base.

Two hypotheses tested in the study were that:

1. externalisation of innovation is increasing;

2. there would be differences between the two industries.

The hypotheses were derived from other studies which considered the industrial and political contexts to industrial innovation. These indicated that innovation strategies in the two industries were likely to be influenced by the following factors:

* the increasing pace of technological change (Dosi 1984);
* the changing environment of manufacturing and service industries, particularly the opening up of new markets (DTI/PA 1989);
* well documented evidence of changing forms of industrial organisation including inter-firm collaboration, and joint

ventures between universities and industry (see Lawton Smith et al 1991);

* internationalisation of R&D; knowledge has become international (Nelson 1984);
* increased pressure on universities and national laboratories to get funding from industry as national research budgets decrease (Charles and Howells 1992);
* exhortations from national governments to exploit scientific capacity (e.g. UK, 1993 White Paper "Realising our potential", France, 1992 Ministere de la Recherche et de la Technologie, (MRT) publicity document, Belgium, 1983, Conseil National De La Politique Scientifique);
* the impact of national, regional and EC funding for supporting collaboration between firms and the science base, and in the case of the last, between countries (Georghiou et al 1992);
* imperfect information (Dosi and Orsenigo 1988);
* spatial imbalances in access to information (Goddard et al 1986).

THE REGULATORY FRAMEWORK

Introduction

The regulation of the interface between public and private technology operates through a variety of country-specific factors and international mechanisms and measures. They include actions taken by government ministries and their agents which make decisions on resource allocation for science and engineering research and their use, other government functions such as those which determine property rights such as patent laws, and in Europe, the European Commission (EC). Here three dimensions of regulatory action are discussed.

Firstly, if the regulatory authorities' view is that the cause of market failures is that the science base is insufficiently responsive to the needs of industry, then they can introduce corrective actions to encourage the science base to re-define its objectives, and set levels of expenditure to meet particular targets.

In the UK, reassessment of the role of the science base culminated in the 1993 White Paper. This has been described as the most significant turning point in Government support for science, engineering and technology for the last twenty years (Shotton and Hillier, 1993,3). The subsequent redefinition of function of a major funding body is clearly spelt out in the SERC's third Corporate Plan (1993). Six strategic aims are identified. These include a "funding of a portfolio of excellent research which contributes to both advancement of knowledge and economic and social advance. To achieve this, the balance of basic to strategic research will be 40:60, and there will be a commitment to improvement of technology transfer within the "science and engineering base" and to industry (page 4). A further change is that the Government is now urging the SERC, and other funding bodies to operate in an open market and fund research in a wider range of institutions and organisations (page 7).

France has also encouraged exploitation of publicly funded research in the last two decades. In 1981, the CNRS created a major division for the exploitation of science with the objective of promoting links with industry (Borde 1992).

In Belgium, regulatory change was directed at the universities at a similar time to events in France. A national policy decision was taken in the early 1980s to encourage the universities to be "innovative" (Van Geen 1991). This was in the belief that industry needed the universities because they could not master the changes in technological processes of the "technological revolution" by themselves. Universities were thus encouraged to ally themselves more closely with the needs of industry. The pressure to obtain money from industry has radically shifted the balance from "fundamental" to "applied" research, funded by regions since 1989.

The level of public funding to support research in the science base is a controversial topic. International comparisons of research and development expenditures are subject to difficulties based on definitional problems and practices in funding (Atkinson et al 1990). Whether or not the problems facing the science base in the UK are in reality any worse than in competitor countries, there is evidence that funding for civil research as a proportion of GDP, (with cutbacks in university funding) in the UK is falling, at a time when expenditure by competitor countries such as France is increasing (SBS 1993).

Secondly, the management of allocation of funds and direction of academic research are important determinants of interaction. A methodological problem in this kind of research is that university research systems are not comparable, one factor being the variations in the sources of funding for research available to the science base. This is illustrated by the differences between the UK, France and Belgium.

In the UK, there is no research ministry or overall research budget as there is in France (Charles and Howells 1992). Academics can bid to the five research councils for funding, to charities, and other government departments, such as the MoD and DTI, EC and industry. Co-ordination is through interdepartmental committees serviced by a Chief Scientific Adviser, who also services the Government's top advisory body, Advisory Committee on Science and Technology (ACOST).

Academic research of interest to the flow measuring industry is now funded by the Integrated Control Systems Engineering Committee (ICSE) within the Engineering Research Commission. Until August 31 1993 it was under Joint Framework on Information Technology (JFIT) in the IT division. Funding in 1993/4 was higher than previous years: £6m compared to the usual level £3-3.5m. It is likely that funding will return to that level. For the one year, the Engineering Board made a special plea for funds. The Committee feels that more work could be done in the area. Its Secretary has described it as a strategic area since a small amount of work on process control can save a lot of money for user firms (personal communication).

Research in electronics is co-ordinated through the seven Information Technology Advisory Boards of the Joint Framework on Information Technology (JFIT). JFIT is "The mechanism which brings together DTI and SERC to co-ordinate their activities in IT". SERC provides funds for academic only programmes such as Silicon Devices and Processes (SIPD) and Novel Systems on Silicon (NSOS).

In France, universities are funded by the Ministry of Education. This Ministry is not a major source of research funding. Research in universities is funded through association with the CNRS.

Belgium has an increasingly complex system of research funding. Due to federalisation, funds are administered by the regions (Wallonia, Flanders and Brussels). Several regional sources can be applied to. For example, the Ministries of Science in Flanders and Wallonia fund research for projects lasting up to six years, which includes staff and capital costs, The Institute for Agriculture and Industry provides funds for PhD students. In a move to ease the tensions between IMEC and the universities and increase co-operation, since 1992, 10% of IMEC's research budget is to be spent in the universities.

Thirdly, where public authorities consider that the problems lie primarily with industry, in that they are not sufficiently active in appropriating the potential resources because of information and/or price constraints, then measures can be introduced to overcome barriers. If high price is believed to be an important cause of market failures, authorities have the option of ensuring that research in universities and national laboratories is relatively cheaper than in-house research. This can be achieved through such actions as determining amounts of capital for investment in the infrastructure, salary levels, or reducing the marginal costs of research undertaken on behalf of industry by subsidies such as industrial research support programmes. Price is also determined by the level of overheads charged by individual institutions.

The main difference between the UK, France and Belgium in the forms of support is that regulatory practices designed to support technology transfer have also devolved to the regions in Belgium, but not in the UK and France, where programmes are co-ordinated at central government level. The UK, unlike France and Belgium provides (with a few exceptions in both) industry specific industry/science base support schemes.

A major UK mechanism is the LINK programme. LINK provides joint collaborative programmes funded through several ministries, including Health, Department of Trade and Industry, and Defence.

One such programme was directly related to the flow measuring industry: The (Joint) Industrial Measurements Systems (IMS) Programme. This is now closed and a new LINK programme, building on IMS and Technology for Analysis of Physical Measurement (TAPM) has been proposed. It has yet to be approved but the likely starting date is 1994.

In electronics, there have been in recent years a number of industry/academic programmes and industry-only Advanced Technology Programmes (ATP) initiatives aimed at key themes in optoelectronics and microelectronics. In the past year, the number of new projects started has been severely reduced, largely because of economic constraints. The consequent need to prioritise areas for support has led to the early closure of a number of programmes. Furthermore, the change in government policy as laid out in the White Paper has meant that, as from September 1993, LINK will be the only national collaborative R&D mechanism (Eddison/JFIT 1993,11).

Collaborative Awards in Science and Engineering (CASE) funded by SERC, and the Teaching Company Scheme, jointly supported by SERC and the DTI, are examples of other mechanisms for joint industry/science base collaboration.

France has a centralised system of "consolidating and managing the entire range of resources" which are allocated for civil R&D. This is the Civil Research and Development Budget (BCRD). Innovation support is primarily through Ministry of Research and Technology (MRT), centrally and through its regional offices, and the 24 regional offices of the Agence Nationale de Valorisation de la Recherche (ANVAR). ANVAR's function is to encourage the transfer of technology out of the science base, and secondly to provide financial support for innovation in industry, by supporting up to 50% of project costs, the EC limit. The CNRS works closely with ANVAR.

The MRT also supports the Industrial Conventions through Technological Research (CIFRE) projects and funds doctoral candidates. This is an equivalent to CASE. France also operates a research tax incentive which has the objective of promoting research and development by Small and Medium Sized Enterprises (SMEs). It works by the government funding the increase in R&D spend from one year to another.

In Belgium the IWT (Flemish Research and Technological Development Fund) was established in January 1991. Equivalents exist in Wallonia and Brussels. IWT is a bridge between universities and industry, providing financial assistance to the interface between industry and universities, typically where industry tries to enter the EC schemes - sometimes they need help in establishing their own research programmes. Assistance takes the form of (i) grants for pre-competitive industrial research and (ii) interest-free loans for the development of prototypes or new manufacturing processes in Flemish industry. In the case of (i) the maximum rate of award is 50% of total project costs; in the case of (ii), the maximum award is 25% grant equivalent, where projects are successful and 40% grant equivalent when projects meet with failure. A further 10% is available in certain cases. These include SMES, when the total eligible project costs exceed 50% of the applicant firm's R&D expenditure for the current year; or is explicitly linked to a current EC project or programme.

A powerful incentive on industry/science base interaction is the growing EC budget for the support of R&D. However, the EC operates its own policies of inclusion and exclusion, for both firms and industries. For example the British computer firm ICL was excluded from Jessi (Joint European Submicron Silicon Initiative) after it had been taken over by Fujitsu. Not surprisingly given the disparities in size and economic significance of the two industries, less support has been given to the flow measuring industry by the EC than to the electronics industry. The Measurement and Testing programme (BCR) was allocated only 140 MECU under Framework III, far less than the Information Technologies budget of 1352 MECU. This is set to rise in 1994, as a recognition of the newly activated demand for innovation support.

To sum up, due to a number of interacting forces, policies designed to refocus university research to *encourage* active participation in a redefined market is a well established pattern in each of the three countries.

RESEARCH FINDINGS

Industry differences

Not only are there general differences between industries in their degree of coherence and technological innovation (Albrechts and Mair 1990, 19), industries are composed of a wide range of product areas which vary in their degree of technological sophistication and obsolescence. The electronic components industry is an extreme example of an industry with a spectrum of technological sophistication. The pace of technological change is rapid in such product markets as semiconductors, whereas other components such as connectors evolve at a much slower rate. New markets are emerging in for example automobiles, HDTV and space. Major characteristics of the UK industry which are critical in this discussion are (i) the reduction of the number of UK firms undertaking research into silicon technologies, (2) reduced levels of defence spending, and (3) the mixed strategies towards university research by foreign owned firms.

On the other hand, the flow measuring industry is a mature industry with a historically slow pace of technological change. However, this is changing. Although large sections of the industry still compete on price, a number of radical forces have reconfigured markets nationally and world-wide in which the use of electronics and software in the meters are key competitive weapons. These include British Gas's inititative on the development of a new meter, and the privatisation of the water industry which released capital, some of which has been invested in new meter designs.

Coherence as a feature of industrial organisation is an important issue. The degree to which an industry has an identity or is fragmented can be a critical factor in shaping the form of regulatory action. Where an industry is fragmented, it is a less obvious target for government support. Fragmentation also reduces the ability of an industry to organise its representation on key institutional bodies, and so take part in the regulatory process. An indicator of this is the much greater involvement of electronic components firms on the UK's SERC committees than those in the flow measuring industry.

Firm Differences

Successful innovation involving external research support requires appropriate management strategies. These include top management commitment to, and visible support for, innovation; long term corporate strategies in which innovation plays a key role; and long term commitment to major projects (see Rothwell 1992, 227). While this managerial approach is well rehearsed in the literature, it is limited as an explanatory framework for firm differences because of a complex set of factors which operate to interfere with the ideal situation. These include cultural differences, imperfect information (see Dosi and Orsenigo 1990) and ability to pay, which can be as much to do with characteristics of the industry and science base and government policy, as those of individual firms. Moreover, where there are market failures at the level of the firm, there are also educative possibilities for public authorities.

The next section discusses these issues using findings from the two samples. First the extent of links with the science base is described; second, the gains which firms had obtained from interaction in both industries, and third, the issues which firms identified as arising from those interactions. The following section describes the perspective from the science base.

The Flow Measuring Industry

From Table 1 it can be seen that the majority of firms, with the exception of the flow measuring industry in Belgium, have some form of links with universities and/or national laboratories. All but one of the UK sample have some form of university link. Only one has collaborative activity with the National Engineering Laboratory (NEL), although all firms have some interaction with NEL because of its calibration and testing function. Some are involved in its user liaison group which meets in different locations throughout the UK. Eight of the UK and one of the French firms in the sample belonged to FLOMIC. Only one of the five French firms had no links at all. One Belgian firm funds university research.

Table 1. Industry Science base links in the flow measuring industry
Source: Author's survey

	UK	FRANCE	BELGIUM	TOTAL
Sample size	13	5	7	25
University Link	12	4	1	17
National Lab link	1	0	0	1
National Funding	3	2	1	6
EC Funding	0	0	0	0

A small proportion of firms in each country had funding for collaborative research from national/regional governments but none of them had money from EC programmes.

The first hypothesis was that there would an increase in links between firms and the science base. That has not happened in the UK sample. In the UK five firms have decreased the level of their direct contact in the last five years. On the other hand, others which had no formal research contact with universities have instituted programmes. One factor was that membership of FLOMIC became a substitute for direct funding. In France, the picture is of one of increasing contact albeit from a small base. In Belgium, the one collaboration is recent and continuing.

It is possible to detect two kinds of relationship. The first is where there is active long term collaboration which is of strategic importance to the company. This occurred in four cases in the UK sample, involving six firms, two in France and one in Belgium. The second is a very different variety, in which academics undertake short term problem solving. This sometimes involves students undertaking projects within the company, involving testing or just informal contact by phone. This characterises the links of seven of the UK sample, three in France and one in Belgium. Mostly these firms were the production sites of multinational companies. However, the majority of respondents, mainly technical people, could see a commercial advantage in interacting with the science base but were prevented from organising interaction because of decisions made elsewhere in the company.

The tendency for a small majority of the UK sample is, therefore, to use the science base when problems need solving rather than using them as part of a portfolio of innovation activities.

The mixed pattern produced the following reactions to the question which asked firms to describe the gains stemming from their interactions with universities.

UK:

- means of catching up on developments in flow metering;
- development of research geared to improvements in meter design;
- assistance in new product design, evaluation of techniques which might be useful to the company, possible recruitment from the university involved in the project;
- early familiarity with relevant technology;
- FLOMIC was potentially a very important means of getting support for R&D projects within the company, their reports were popular within the company, and membership brings status;
- impact on competitiveness of companies subsidised by LINK, and an enhancement of their in-house product research;
- investment in new technology which a company can license to other companies, but which needs further development;
- benefits of a new product and the supply of services to go with the product;
- potential technical solutions and a better product.

France:

- company expects a new product to be developed in conjunction with university to be important in the competitiveness of the company;
- improved products, long term access to university expertise;
- short term problem solving means that company does not have to recruit engineers;
- inputs into understanding principles behind flow profiles such as the contacts provided by FLOMIC.

Belgium:

- company image has grown through association with university, and their market position has improved.

Electronic Components

In this industry, a higher proportion of firms in each country have active contact with the science base than in the flow measuring industry (Table 2). Several UK companies have links with UK national laboratories, and one has a contract with LETI. Only one of the French firms currently has research links with LETI, and two firms in Belgium have links with IMEC.

Table 2. Electronic Components Industry Links with Science Base
Source: Author's survey

	UK	FRANCE	BELGIUM	TOTAL
Sample size	10	5	7	22
University Link	9	3	6	18
National Lab. link	6	1	2	9
National funding	8	2	3	13
EC funding	7	1	3	11

Most firms prefer collaboration, particularly subsidised collaboration to direct funding of university research. In the UK this is through LINK and/or EC schemes. Collaboration has become so popular with UK firms that the UK has the largest number of collaborative links of any member state (Georghiou et al 1992, i).

Changes in market orientation due to such factors as the decline in protected markets in defence, and decreased investment in silicon research, has caused three of the UK firms to reduce their level of interaction. However, two with corporate headquarters overseas (Canada and Japan) are looking to increase the use of university research. In France, the most common factor in whether links were made at all was the function of the manufacturing site within the corporate organisation with regard to research and development. Several of the firms visited had research centres elsewhere. However, some firms were unable to interact with the science base because they were not aware of what work was being done.

The major difference between this and the flow measuring industry is the level of commitment of industry to long term research collaboration: very few see the science base as a resource for short term problem solving. This is reflected in a few of the responses to the question of what the gains were from working with the science

Table 3. Critical issues relating to industry links with the science base in the flow measuring industry

Critical issue	**Main Concerns**
Science base	- FLOMIC was dominated by academic interests
	- FLOMIC should have been more driven by users
	- differing timescales (5UK)
	- universities out of touch with industry
IPR	- neither side wish to lose control over commercial rights, and secrecy (7 UK, 1 France)
	- patent rights issue with one UK laboratory
	- academics refuse to consider potential for commercial exploitation.
	- universities rapidly becoming more expensive
	- firms more likely to consider relative cost advantage of different universities.
Funding	- low level of take-up of UK LINK funds
	- complexity of LINK rules inhibits take-up
	- return to near market support e.g MAP favoured
	- LINK does not fill the gap it was supposed to
	- small companies do not have resources to enter programme
	- Large French firm has several projects funded by MRT
	- three firms knew of no means of getting money out of public authorities
	- lack of coordination of industry by public authorities
	- Wallonian government provided appropriate support
	- no EC funded projects
Company specific issues	- limitations on R&D budget (6 UK)

base. There were some country-specific differences. The French university system appears to be less accommodating to industry for historical reasons than the UK and Belgium. The largest firm in the sample identified the problem as being that the universities were less technologically orientated than those in other countries, so research links were increasing with universities outside France and include Cambridge (UK) and MIT (USA), and because the universities are too poor to publicise their activities.

Below are some of the gains from interaction identified by the sample:

UK-

- important to current and future competitiveness;
- universities provide complementary expertise, at a basic scientific/theoretical level;
- universities undertake longer term research, ahead of time of industry needs, thus reducing industry's risks of investment in areas where there may be no payback;
- the firm feeds the results of academic research into in-house R&D programmes to improve materials, devices and other products;
- universities solve genuine industrial problems;
- recruitment of academic personnel;
- access to international university networks;
- kudos, one of the UK sample has several deals with LETI and spoke very highly of the work gains from finding out what the big players are doing.

France-

- improvement in competitive position and possible recruitment;
- basic research inputs and recruitment;
- buys time, understanding of basic principles.

Belgium-

- effective externalisation of entire R&D effort to IMEC;
- IMEC as an extension of its in-house effort. It has enabled the company to participate in international programmes and broaden the scope of its research activities;
- short term product solving plus some longer term research results;
- recruitment.

Issues

A number of themes arise from the comments from both industries. These are illustrated by Tables 3 and 4 which identify the concerns expressed in each industry about working with the science base.

One important difference in outcome of interaction is that the electronic components industry identifies recruitment from the science base as a major advantage. This enables firms to maintain a high level of internal R&D effort. This is in contrast to the flow measuring industry where by and large, exploitation of the science base is a substitute for in-house activity, and recruitment is less.

To illustrate this point, one UK electronics components firm described its relationship with universities as one maintaining a number of strategic alliances. However, its main interest is in specialist skills, rather than the licensing of technology. The company considers what technical skills are on offer and how appropriate they are. It has been a problem for the company that on more than one occasion the university lacked the right kind of equipment but had the skills the company needed.

A second important issue is that of intellectual property rights (IPR). IPR arrangements are a source of much conflict in university/industry interaction in both industries. Neither side wish to lose control over valuable knowledge, and industry is especially concerned about maintaining commercial secrecy. One industrial respondent suggested that universities should not seek to own the IPR but should really be asking for a fair share of any royalties in the event of exploitation. A particular concern for academics is the loss of control of the know-how which pre-dated a research contract with a firm.

A third issue is that of the level of public subsidy. The two samples exhibited significantly different regulatory conditions in this respect. The low level of targeted support for the flow measurement industry has had the effect that firms in the UK flow measuring industry have not learned the rules of the funding game. They complain that the complexity of LINK rules has inhibited interaction between universities and industry at the "pre-competitive" level. The

Table 4 Critical issues relating to industry and science base links in the electronic components industry

Critical issue	Main concerns
Science base	- decreasing manufacturing capability in some sectors in the UKaffects universities ability to maintain facilities affects level of research and funding - this means that students cannot be trained in the latest processes. - one UK company gives out of date equipment to universities - Specialist skills not technology critical factor - UK laboratories very expensive because of overheads charges and can be very slow in producing results - important co-ordination role of LETI - poverty of universities means that industry funding is viewed as a means of solving their problems - French universities do not have the resources to publicise their activities to industry - French universities are less technological than universities for example in the UK and USA. - research links are sought outside France - secondment into universities is a strategy to optimise use of public facilities (cost saving) - cost becoming more important in UK - university research in Belgium is 60% cheaper than in-house R&D for one firm
IPR	- a greater problem in the UK, than France and Belgium - two foreign owned firms UK located said that they had no desire to tie IPR
Company specific factors	- company commitment to internal R&D and capital equipment restricts funding of university infrastructure - one Belgian firm externalises all R&D effort to IMEC
Public subsidy	- UK and EC schemes used by majority of UK sample - UK firms critical of LINK rules - One French firm's central research laboratory receives up to 50% of R&D budget from French and EC funds. - one Belgian firm receives between 3-40% of R&D funding from regional, national and EC initiatives - EC schemes viewed as superior to nation schemes in each country - enforced international collaboration brings together firms with complementary interests - EC creates networks

Department of Trade and Industry is seen as being remote from the needs of industry and the science base. This pattern of a lack of institutionalised externalisation is in sharp contrast with the electronic components industry. However, FLOMIC was given pump-priming funds by the DTI when it was formed.

On the other hand, even the electronic components firms in the UK which have LINK funds are highly critical of the way the scheme operates. The 50% rule has the effect that the larger the science base share of project expenditure, the smaller the net grant to the industrial partners. The danger is that universities could be brought in just to satisfy LINK conditions, and not used effectively.

However, LINK can be a useful mechanism for those firms pre-disposed to collaborate which have the information and time resources to apply, even in the flow measuring industry. A very successful project in the sample is between a user, manufacturer and a university. For the company the project is a means of developing a device using information technology with applications in flow measurement, and of cost saving, (R&D as such is no longer undertaken internally). It also was a means of developing their own staff through contact with able people, their learning to manage collaborative projects and keeping up to date with developments in technology. The critical factors were (1) ease of getting a LINK project (one of the employees chairs a LINK programme so the rules of the game were known), (2) the university appreciated the commercial need and had people who wanted to see the applications of the work, and (3) the industrial partner had a good device to work on.

International schemes have been generally commended by electronic components firms in each country as being superior to national initiatives. The level of funding is seen to be more appropriate. In addition, the enforced collaboration with companies outside the home nation may give rise to a better structure within consortia - where partners with complementary rather than competing interests are brought together.

To sum up this point, experience in the electronic components industry suggests that national and EC schemes are very effective in creating networks and providing important learning experiences.

Table 5 . Critical Issues relating to academic interaction with the flow measuring industry

Critical issue	Main concerns
Funding	- under-funding of research means that UK staff have to be paid on short-term industry contracts - industry sees UK universities as a cheap way of doing research - it takes time to develop long term relationship with industry in France and for industry to pay for more than short term contracts in national lab. - CERT competes with universities, where research is cheaper as staff costs not fully costed. - university long relations with MNC on solving fundamental research problems - Belgian academics accept short term links with industry as part of life.
FLOMIC funding	- FLOMIC funding had the objectives of keeping academic research at front end - small amount of funding for projects (c #15k) - gains for departments more in terms of spin-offs for research than financial - created intelligence network - FLOMIC under resourced, and firms unwilling to put up funds for larger projects
Perceptions	- gap in understanding by industry in the UK of the stage to which university can take project to (i.e. prototype) - industry in the UK does not realise that the stage after prototype is very expensive - Belgian industry views university as a public service
Industry failures	- UK industry not capitalising of position of leading manufacturing by under-investment in R&D - lack of representation on key research committees by UK firms - UK industry tends to skimp on engineering stages, foreign firms e.g. Japanese produce better engineered products - R&D departments in some UK firms weak, lack of management understanding of role of expert in the university and the firm, short term horizons
Under-utilisation of research expertise	- ideas left dormant, creativity stifled in UK universities by over commitment to industry problems - industry wants short term not longer term interaction in the UK
IPR	- problem that work is not in the public domain when industry owns IPR in the UK - this leads to loss of control of know how which pre-dated research contract with a firm in the UK - UK firms reluctant to share results to pre-competitive research undertaken by FLOMIC - IPR wanted by Belgian firms
Government support	- UK academic's research stymied by refusal of DTI to fund near market research

The Academic Response

On the flow measuring side, the sample included six UK departments and two national laboratories (Harwell and NEL), one French university department and two national laboratories, and two university departments in Belgium. In electronics, the UK sample included four universities and two national laboratories (Harwell and RSRE Malvern); in France, one university and one national laboratory (LETI); and in Belgium, four departments and one national laboratory (IMEC).

The critical issues relating to industry links with the science base in each industry are shown in Tables 5 and 6.

The responses from the academic community in the UK which interacts with the flow measuring industry are mixed. On the one hand, industry money funds research in flow measurement that otherwise might not be undertaken, but on the other it has effect of tying up intellectual property, and ignoring research which could be theoretically significant but which has no obvious short term payback. The consequence is an under-utilisation of research skills and equipment. The university academic interviewed in France was more positive because the expectations of the industry are different. This reflects the orientation of the university system towards longer term research. However, CERT is affected by terms of trade set by the state. Research is cheaper in the universities as the staff are on the establishment and are not dependent on industry for their posts, unlike in CERT where the majority are on industry funded contracts. Hence CERT expertise is under-exploited because there is a cheaper option.

In Belgium, pragmatic considerations shape the views of academics who accept the necessity of industrial funding. However, there was some suggestion that industry still sees universities as providing a public service and are reluctant to pay a commercial rate.

In electronics, the leading edge is in both industry and the universities. The problem facing universities in each country is that capital investment in key technologies, such as silicon, is not keeping pace with those in industry. The effect is that up to a point universities

Table 6. Critical issues relating to academic view of interaction with the electronic components industry

Critical issue	Major concerns
Value from interaction	- structures to work on - future tied up with industry, therefore want to work on similar problems - work keeps academics in contact with where industry is going - equipment donated by industry - value of tenure system is that it allows freedom of research - CASE excellent way of establishing links with industry - IMEC undertakes research 5-10 years ahead of industry needs
Drawbacks	- choice of project has to be dictated by what will be interesting to industry - research becoming more short term - dependence on industry for materials and industry's own resources - rapid changes in industry's research interests - over commitment to industry can handicap personal professional advancement - over commitment to industry cost Edinburgh central funding status of Micro fabrication Facility - changing role of UK national laboratories forces competition not collaboration with industry - some departments in Belgian universities obliged to work on short term applied problems - others able to chose longer term projects
IPR	- freedom to publish - difficulty in defining what might be commercial outcome of fundamental research - delays caused by working out IPR allocations - policy in Leuven if industry pays, IPR for only one year after project ends
Co-ordination	- insufficient cross-fertilisation of ideas between research teams in the UK. - joint DTI/SERC co-ordination could create a stronger community - stronger community would increase competitive position of UK universities with IMEC
Funding	- LINK biased in favour of industrial partners - level of overheads to be charged to industry. - SERC money is fundamental, EC or industrial work could not be run without it - lack of equipment, reduces competitiveness with other universities - underfunding of French universities - Belgian universities underfunded
Industry problems	- lack of high level researchers in UK industry - cutbacks in funding from UK firms

have concentrated on basic research, and industry on development. This implies a complementary relationship, but it also means that students are not trained in the latest processes and that possibilities for research are limited. Universities are strategically important to firms at the sharp end of this industry in the UK. It was suggested by one respondent that all the electronics industry keeps an eye on what is happening in universities. CASE was cited as a means of giving access to academics.

In France, the interaction of state owned firms with LETI is a long term strategy. The problems for LETI and for the universities are the familiar ones of exploiting their scientific resources, and being driven towards shorter term research.

In Belgium, academics' ability to control the amount of industry work depends on the laboratory. Even where academics have been able to establish a system which allows both industrial and fundamental research to be undertaken, one said, "There is never money enough to do work by yourself without interference of industry. The question is, what is the minimum amount needed to be able to do so?" IMEC is also facing the problem of being directed towards shorter term research.

It is a current concern whether long term academic research and commercial activities are compatible (see Feller 1990,343). Feller has recently argued that "The existing tracks upon which academic research flows to the market are likely to become blocked if not broken apart as universities limit existing flows of information in order to divert faculty findings to specific firms. The consequence is lower rates of technological change" (Feller 1990 p.343). In this study, this problem has manifested itself through problems of IPR in both industries, particularly in the UK.

The situation on IPR is somewhat more relaxed in both France and Belgium than in the UK. This can be due either to pragmatism, i.e. that universities are in a weak position, or to the fact that companies can reach agreement more readily over what constitutes commercial rights. An example of how agreement can be reached is to be found in the Applied Sciences Faculty at the University of Leuven. This operates a policy that if industry pays then they have the IPR for one year only after the project ends.

THE EFFECTS OF REGULATION AND POLICY IMPLICATIONS

This paper has been concerned with the regulatory effects on the relationship between industry and the science base. The first conclusion is that regulation has caused the science base in each country to be increasingly caught up in an information market. This is especially true in the case of electronics. The findings suggests that there are contradictions in government policy in which exploitation is a priority, the consequence of which is a loss in the externalities generated from public funded science.

The difficulties identified by academics in this study suggest that a market is evolving, but that it is one in which price cannot be the only criterion for trade. Price is a major factor, especially where profits are squeezed in markets where economic rent is not derived from technological advantage, and where firms believe that they can obtain equivalent inputs from institutions outside their national space. This case is illustrated by one of the UK water companies, whose international activities have been matched by a readiness to look for expertise outside the UK. Absolute and marginal costs for industry of interacting with the science base are therefore an increasingly important determinant not only of the degree of interaction, but also of the location of interaction.

A second conclusion is that each country provides a different level of uncertainty to industry, both in the kind of research undertaken and in the skills of scientists and engineers in the universities and national laboratories. The assumption has tended to be that technology is transferred out of the science base, whereas in reality, what is increasingly happening is that the ideas and problems of industry are first transferred into the science base. This reduces the level of uncertainty to industry because the public sector shares the costs of investment. In the case of electronics this has a major impact on the extent to which academic research priorities have been shaped by the demands of industry. The evidence in this study suggests that there is a danger of over-use by industry. In the flow measuring industry, the picture is one of some successful interaction where there are gains on both sides, but the overall pattern could be described as one of an under-utilisation of expertise.

Although some of the market failures identified in this paper arise out of industrial circumstances, they also arise out of the lack of public authority interest in the needs of the more mature sections of the manufacturing base. The case of the flow measuring industry in the UK is an example. Under-investment by the state in both engineering technologies in universities and near-market research in industry increases firms' technical uncertainty. The calculation of opportunity costs and benefits of using the science base is therefore difficult for firms to assess. UK policy has been addressing the issue from the wrong point of view. In order for industry to take advantage of technology developed in the science base, the reasons for their low levels of technical competence should be addressed. There are good reasons why development in engineering technologies in universities and national laboratories could be seen as a public good in the same way that leading edge physics research is.

In sum, in the electronic components industry, it is the way the research base is organised rather than the industry itself which provide some of the more interesting issues. This is because each country has regulated the supply of technology to this core area of industry quite differently. A major difference between the UK and Belgium is the existence of IMEC. What Belgium and France do have in common is the concentration of resources in national laboratories such as LETI and IMEC. The pattern in the UK is one of fragmentation of resources. However, UK, Belgian and EC strategies to increase the flow of information between the electronic components industry and the science base and create a culture of joint research activities has positive externalities for firms located in other countries. This is where they find that entry barriers in terms of academic expectations have been lowered.

In the flow measuring industry, in the absence of a supportive regulatory framework, it is the changes in the industry as a whole and the firms themselves which have a greater impact on relationships with the science base. There has been a small impact on interaction in the UK through LINK, but the effects of FLOMIC may last ten years, a gain from a regulatory measure.

The study identified a major factor influencing exploitation of the science base as being interaction between people in industry and the science base. Interaction creates essential networks, provides vital training for both academics and industrialists, and gives critical insights into the respective roles and expectations of participants. Experience in France and Belgium, particularly with respect to the two major research centres, LETI and IMEC, has shown how government-supported initiatives can be effective in generating an interface between academics and industry by subsidising the placement of scientists and engineers in the complementary environments.

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